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INFRARED EMISSION AND EXCITATION IN LMC HII REGIONS

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ABSTRACT. The infrared excess (IRE) of LMC HII nebulae is found to correlate positively with the temperature of the ambient radiation field or with the He^+/H^+ abundance ratio. This result is discussed in terms of a selective absorption of the photons in the range 504-912Å relative to the He ionizing photons. This interpretation may explain the paradox of finding highly excited nebulae with only relatively moderate equivalent width of their Balmer lines.

1. INTRODUCTION

The excitation in HII nebulae is sensitive to the metallicity and to the energy distribution of the radiation field in the far UV ($\lambda < 912$Å). The metallicity as traced by the abundance of oxygen is known to be fairly uniform across irregular galaxies in contrast to the case of spiral galaxies. Thus restricting to a sample of HII nebulae in the Large Magellanic Cloud allows the study of the relative variations of the temperature of the radiation field from nebula to nebula, minimizing any possible influence of abundance variations.

2. OBSERVATIONAL DATA

The IRAS AO maps of the LMC (P. Schwering, in preparation) have been analyzed in order to separate the emission originating from sources and the underlying diffuse large scale component. About 200 sources have been identified with HII regions outside the 30 Doradus region (Ungerer et al., in preparation). In this catalogue we have selected the HII regions detected in the 5 GHz radio continuum survey (McGee et al. 1972) and having optical spectroscopic measurements (Pagel et al. 1978 and references herein). We rejected the source N44 whose radio continuum flux is contaminated by the SNR emission. For the HII nebula N91 an extended north-south plateau shows up at 5 GHz in contrast with the infrared and 408 MHz emission. We thus used the 408 MHz flux density. We have redetermined the electron temperature, the abundance of He^+ relative to H^+ and O/H in a homogeneous way using the atomic data compiled by Mendoza (1983). The ambient radiation field in an HII nebula can be conveniently characterized by an effective temperature T_{eff} which measures the relative number of the photons shortward of 504Å to those from 504 to 912Å. Stasinska (private communication) has demonstrated that this quantity is relevant for the excitation of nebulae, no matter if there is one or several exciting stars and which stellar atmosphere model is used. Thus we have defined T_{eff} for the ambient field inside a nebula as the T_{eff} of a stellar atmosphere model having the same ratio of He to H ionizing photons. Based on the NLTE stellar atmosphere models from Mihalas (1972) and the grid of photoionization models (Stasinska, 1982), we assign to each nebula of our sample a T_{eff}, this temperature reflecting directly the temperature of the ionizing star cluster if there was no dust mixed with the ionized gas. This T_{eff} has been determined from the relative intensities of [OII]3727, [OIII]4363, [OIII]4959+5007 and Hβ4860, and we checked that it was also consistent with the He^+/H^+ ratios (Fig. 1).

The total infrared emission has been determined by multiplying the sum of the four in-band fluxes with a bolometric correction factor of 1.8: this factor is actually insensitive to the dust temperature over a large range of values from 30 to 200K (Boulanger, private communication) allowing us to get reliable bolometric infrared emission for HII regions. The IRE is deduced: by definition it has a value of 1 corresponding to all the bolometric infrared luminosity originating from Lyman α absorption (we further assumed that all Lyman continuum photons which ionize the gas degrade into Lyman α photons).

3. RESULTS AND DISCUSSION

In Fig. 2 the comparison between the IRE and T_{eff} is presented. The IRE tends to increase with the radiation field temperature. More striking is the very similar correlations in Fig. 1 and Fig. 2 which indeed implies that **the IRE correlates positively with the He^+/H^+ ratio.**

If the absorption of Lyc photons by dust were negligible, the IRE would measure directly the contribution of the nonionizing stars relative to the exciting stars ($>15M_\odot$), and we would predict a decrease of the IRE with increasing T_{eff} caused either by different Initial Mass Functions (IMF) or by age effects for the different nebulae. Thus we are forced to conclude that dust in HII nebulae plays a major role for the excitation, and the IRE may not directly reflect the properties of the young star cluster. One explanation for the increase of the IRE with T_{eff} is the existence of selective absorption of the 504–912Å photons relative to the He-ionizing photons. If the 504–912Å photons are preferentially absorbed, the effective temperature of the ambient radiation field will be increased relative to the effective temperature T^*_{eff} of the star cluster. This effect is illustrated in Fig. 3 where we have computed the IRE based on the NLTE Mihalas atmosphere models and ignoring absorption of all photons longward of 912Å. The solid lines are related to the fraction of 504–912Å photons absorbed by the dust, and the dashed lines show the evolution of T_{eff} as the amount of selective absorption of Lyc photons increases.

In Tab. 1 we show the effects on derived star cluster properties for two HII regions with extreme physical conditions when this selective absorption is considered. The IMF parameters (i.e., the slope x and the upper mass cut-off m_U), duration of star formation τ, star formation rate SFR, and the total luminosity are based on an evolutionary model for a star cluster which gives $T^*_{eff}(x,m_U,\tau)$ and $W^*_\beta(x,m_U,\tau)$.

TABLE 1

	N214C		N105	
$T_{eff}(10^4K)$	3.58	3.52	4.3	3.6
IRE (from phot.>912Å)	1.7	0.0	3.7	1.0
Equivalent width W_β(Å)	115	137	85	170
H phot. absorbed by dust	0%	16%	0%	50%
Ionization rate $(10^{50}s^{-1})$	1.0	1.0	2.5	2.5
Stellar Lyc rate $(10^{50}s^{-1})$	1.0	1.2	2.5	5.0
IMF upper cut-off $m_U(M_o)$	40	25	140	35
CSF duration (Myr)	4.5	0	>>10	0
SFR $(10^3M_oMyr^{-1})$	3.9		- -	
Stellar mass formed (10^3M_o)	18	3.0	- -	70
Present day $L_{Tot}(10^6L_o)$	8.1	8.0	- -	25
L_{FIR}/L_{Tot}	0.09	0.10	- -	0.1

Table 1: Correction effects on star cluster properties for the far UV selective absorption: two columns are given for each nebula corresponding respectively to the extreme cases of no selective absorption and Zero Age Main Sequence star clusters. The last six lines of this table are based on a star cluster model very briefly presented in the paper of Viallefond and Thuan (1983) and revised by using the NLTE Mihalas stellar atmosphere model (Viallefond, unpublished). An IMF slope of 1.3 was assumed corresponding to the Salpeter IMF slope for the solar neighborhood: continuous star formation was also assumed. If these two assumptions are relaxed, the star cluster parameters will be different: however it will not affect the conclusions of this paper. An unreasonable solution is indicated by "- -".

Let A_β(radio)-A_β(Balmer) be the apparent "excess" of extinction derived by comparing the extinction A_β (radio), obtained from the relative strength of the Hβ Balmer line to the radio free-free emission, with A_β (Balmer), obtained from the relative strengths of the Hα and Hβ Balmer lines (Caplan and Deharveng, 1985). This "excess" extinction is believed to be at least partly caused by the presence of dust mixed with the ionized gas: it might then be related to the amount of selective extinction. The "excess" extinction for N214 is only 0.16 mag. compared to 0.54 mag. for N105, consistent with our analysis, which suggests very little selective absorption for N214 compared to N105. This trend is supported by the analysis of the full sample. The case of N105 illustrates how partial correction for selective absorption can solve the problem of finding many extragalactic HII regions with high effective temperatures (40,000 to 50,000K) and very low values of W_β (Stasinska and Viallefond, in preparation). On the contrary, less excited HII regions such as N214C can be interpreted without any selective absorption. Another important implication which emerges from this discussion is that a substantial fraction of the nonionizing radiation may escape the ionized regions contributing to the large scale interstellar radiation field in the LMC: only 10 to 20% of the total luminosity from the young star clusters would be degraded into far infrared emission locally inside the plasma, i.e., in the sites of star formation. Finally it is interesting to notice that the absorption efficiency of small graphite and silicate grains (with typical sizes of 30 to 100Å) does peak near 700 to 800Å (Draine and Lee, 1984). In this respect, the study of the excitation in HII regions may give

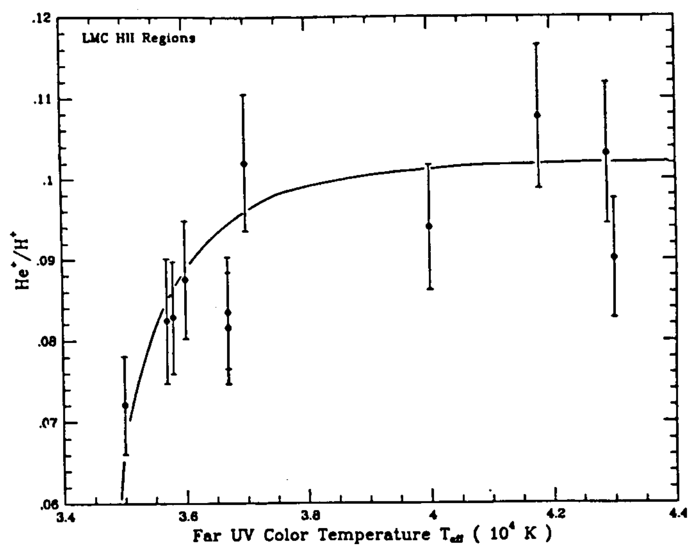

Fig. 1: Abundance of He^{+} relative to H^{+} as a function of the far UV color termperature of the radiation field in LMC HII regions. This temperature is expressed in terms of an effective temperature as defined in the text. The curve is based on photoionization models (Stasinska, 1982).

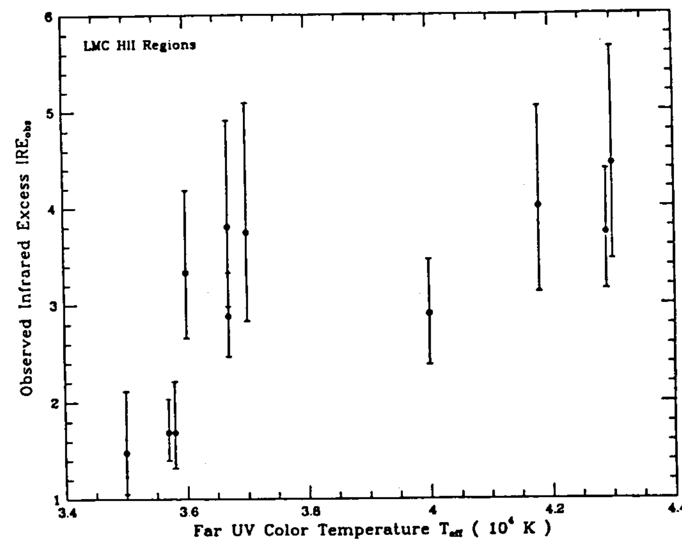

Fig. 2: Observed infrared excess as a function of the temperature of the radiation field in LMC HII regions: the sample of nebulae is common with Fig. 1. All Lyman continuum photons which are absorbed by the gas are supposed to be degraded into Lyman α photons. By definition the IRE is unity if all the bolometric infrared emission is entirely caused by dust absorption of these Lyman α photons.

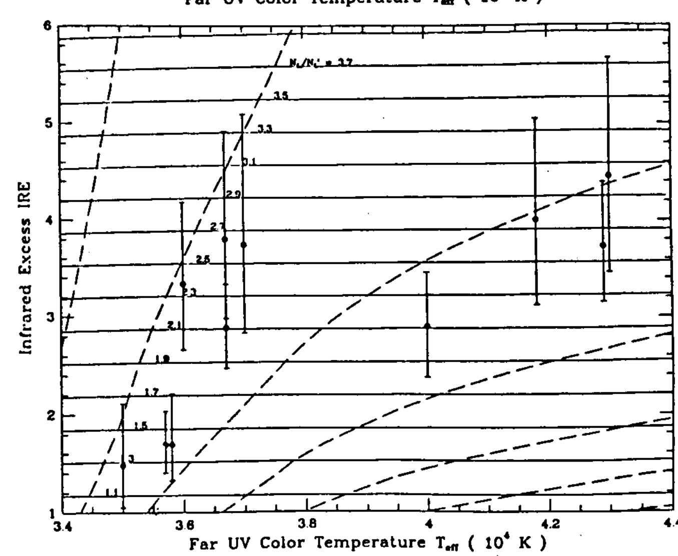

Fig. 3: Grid of a simple model for the IRE if it is caused exclusively by dust absorption of the 504-912Å photons. The dashed lines correspond to the evolution of the IRE and of the radiation field temperature relative to the amount of selective absorption. The continuous lines correspond to different values of the ratio N_L/N'_L of the 504-912Å photons, N_L being the number of these photons emitted by the star cluster and N'_L the number of these photons which effectively ionized the gas. For an IRE of unity the radiation field temperature is equivalent to the star cluster temperature T^{*}_{eff}.

valuable new constraints on the lower part of the size distribution of the grain population. The 2200Å bump of the extinction curve of the LMC is apparently weak (Prevot et al. 1984) compared to the bump for the standard galactic curve (Savage and Mathis, 1979): the properties of the grain population must be different in the LMC and in the solar neighborhood: selective absorption in the far UV would be primarily caused by the small silicate grains in the LMC if the small graphite grains are responsible of the 2200Å bump of the standard extinction curve.

4. CONCLUSIONS

From a sample of LMC HII regions for which all relevant information is available, a positive correlation is found between the IRE and the effective temperature of the ambient radiation field or the He^+/H^+ abundance ratio. We suggest the presence of selective absorption in the far UV to explain this observed phenomenon. While this result introduces a lot of complications for the interpretation of the IRAS measurements of the young star-forming regions in galaxies, it may solve the apparent paradox of finding many highly excited HII nebulae with only very moderate values for their equivalent width of Hβ.

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